

Final Report on Grant NAGW 959

Grant NAGW 959 supported work on studying faint galaxy populations with particular emphasis on the evolution of the populations over cosmological timescales and their contribution to the near infrared background and on studies of the intergalactic. During the 1993-1996 period, we concentrated on the evolution of the luminosity function of galaxies in the rest frame K-band and on the evolution of the galaxy morphology between redshifts of zero and 1.7. In analyzing the evolution of the luminosity function, we introduced the use of the cumulative light density as a function of absolute magnitude (c.f., Cowie and Songaila, 1993, Proc. Nat. Acad. Sci. 90, 4867). This provides a more model independent description of the luminosity function than the more usual parametric fits and also provides a more direct view of which class of galaxies is dominating the light density of the Universe. We have used this method to analyze the evolution in the galaxy properties between 0 and 1 in the Hawaii K=20 spectroscopic sample showing that while the overall light density was a factor of roughly two larger at $z=1$, the average galaxy was almost a half-magnitude fainter. The precise values depend on the assumed geometry of the Universe, but the sense of the effect is the same irrespective of whether the geometry is flat or open. Galaxies were shown to be in a much earlier stage of formation at $z>1$ with many rapid star forming galaxies present.

This work was presented at many international conferences summarized below and in a number of major papers which are included in the summary of papers supported by the grant.

In parallel work, the studies of the IGM yielded the first measurement of extragalactic deuterium to hydrogen ratios, the first measurement of the microwave background temperature and the first detection of metals in the Lyman-alpha forest together with a number of related results with NAGW 959 supporting the interpretation of these important discoveries. Presentations at conferences and publications are summarized on the next page.

Presentations at Meetings and Conferences

During the grant period invited talks were given at the IAP meeting, *First Light in the Universe ...* in Paris (July 1992), at the Neugebauer Symposium *Sky Surveys: Protostars to Protogalaxies* at CalTech and at *The Pontifical Academy* in Rome (both Sept. 1992), at the NORDITA workshop on *Galaxy Formation* in Copenhagen (May 1993), at the 37th Yamada Conference on *The Evolution of the Universe and Its Observational Quest* in Tokyo (June 1993) at the Space Telescope Workshop on *Emission from Quasar Absorption Line Systems* (July 1993), at the Field Symposium on *The Physics of the Interstellar Medium and the Intergalactic Medium* in Elba (June 1994), at the Herstmonceux Conference on *Wide-Field Spectroscopy and the Distant Universe* in Cambridge, England (July 1994), at the Canadian Institute for Advanced Research Meeting on *Theoretical Astrophysics* in Kona, HI (April 1995), and at the 186th American Astronomical Society Meeting *Special Session on Quasar Absorption Line Studies* in Pittsburgh (June 1995). Numerous colloquia were also presented at various places (CalTech, UCLA, Princeton, ESO in Munich, etc.)

Papers Supported in Part by this Grant NAGW-959

1. "Faint Galaxy Surveys," L. L. Cowie and A. Songaila 1993, in *Proc. Nat. Acad. Sci.*, **90**, 4867.
2. "Galaxy Evolution," L. L. Cowie and A. Songaila 1993, in *First Light in the Universe - Stars or Galaxies?*, eds. B. Rocca-Volmerange, B. Guiderdoni, M. Dennenfeld, and J. Tran Thanh Van, (Gif-sur-Yvette: Editions Frontières), 147.
3. "Studies of $z \sim 4$ Quasar Fields," E. M. Hu and R. G. McMahon 1993, in *First Light in the Universe - Stars or Galaxies?*, ed. B. Rocca-Volmerange B. Guiderdoni, M. Dennenfeld, and J. Tran Thanh Van (Gif-sur-Yvette: Editions Frontières), 87.
4. "Near Infrared Galaxy Surveys," L. L. Cowie and A. Songaila 1993, in *Sky Surveys: Protostars to Protogalaxies*, ed. B. T. Soifer, *Astr. Soc. Pac. Conf. Ser.*, **43**, 193.
5. "Galaxy Number Counts from $K = 10$ to $K = 23$," J. P. Gardner, L. L. Cowie, and R. J. Wainscoat 1993, *Ap. J. (Letters)*, **415**, L9.
6. "Upper Limits to Balmer Line Emission in Three $z \sim 2$ Damped Lyman α Systems," E. M. Hu, A. Songaila, L. L. Cowie, and K.-W. Hodapp 1993, *Ap. J. (Letters)*, **419**, L13.

7. "Deuterium Abundance and Background Radiation Temperature in High Redshift Primordial Clouds," A. Songaila, L. L. Cowie, C. J. Hogan, and M. Rugers 1994, *Nature*, **368**, 599.
8. "The Hawaii *K* Band Galaxy Survey. I. Deep *K* Band Imaging," L. L. Cowie, J. P. Gardner, E. M. Hu, A. Songaila, K.-W. Hodapp, and R. J. Wainscoat 1994, *Ap. J.*, **434**, 114.
9. "The Hawaii *K* Band Galaxy Survey. III. Spectroscopy of $K < 20$ Galaxies," A. Songaila, L. L. Cowie, E. M. Hu, and J. P. Gardner 1994, *Ap. J. Suppl.*, **94**, 461.
10. "An Upper Limit on the Density of Low Mass Stars in the Galactic Halo," E. M. Hu, J.-S. Huang, G. Gilmore, and L. L. Cowie 1994, *Nature*, **371**, 493.
11. "HAWAII 167: A compact absorption line object at $z = 2.35$," L. L. Cowie, A. Songaila, E. M. Hu, E. Egami, J.-S. Huang, A. J. Pickles, S. E. Ridgway, R. J. Wainscoat, and R. J. Weymann 1994, *Ap. J. (Letters)*, **432**, L83.
12. "The Microwave Background Temperature at a Redshift of 1.776," A. Songaila, L. L. Cowie, S. Vogt, M. Keane, A. M. Wolfe, E. M. Hu, A. L. Oren, D. R. Tytler, and K. M. Lanzetta 1994, *Nature*, **371**, 43.
13. "Two Extremely Red Galaxies," E. M. Hu and S. E. Ridgway 1994, *A. J.*, **107**, 1303.
14. "The Metallicity and Internal Structure of the Lyman-Alpha Forest Clouds," L. L. Cowie, A. Songaila, T.-S. Kim, and E. M. Hu 1995, *A. J.*, **109**, 1522.
15. "A Population of Very Diffuse Lyman-Alpha Clouds as the Origin of the He+ Absorption in the Intergalactic Medium," A. Songaila, E. M. Hu, and L. L. Cowie 1995, *Nature*, **375**, 124.
16. "Quasar Absorption-Line Studies at High Redshift: Measurements of the Microwave Background and Molecular Hydrogen," L. L. Cowie 1995, in *Physics of the Interstellar Medium and the Intergalactic Medium (Field Symposium, Elba)*, eds. A. Ferrera, C. F. McKee, C. Heiles, and P. R. Shapiro, ASP Conf. Ser., **80**, 463.
17. "Deep Survey of Fields around $z > 4$ Quasars," E. Egami 1995, in *Wide-Field Spectroscopy and the Distant Universe*, eds. S. J. Maddox and A. Aragon-Salamanca, (Singapore: World Scientific), p.380
18. "The Distribution of Column Densities and b Values in the Lyman-Alpha Forest," E. M. Hu, T.-S. Kim, L. L. Cowie, A. Songaila, and M. Rauch 1995, *A. J.*, **110**, 1526.
19. "Faintest Galaxy Morphologies from HST WFPC2 Imaging of the Hawaii Survey Fields," L. L. Cowie, E. M. Hu, and A. Songaila 1995, *A. J.*, **110**, 1576.
20. "Astrophysical Limits on the Evolution of Dimensionless Physical Constants over Cosmological Time," L. L. Cowie and A. Songaila 1995, *Ap. J.*, **453**, 596.
21. "Detection of Hot Gas in the Interstellar Medium," J.-S. Huang, A. Songaila, L. L. Cowie, and E. B. Jenkins 1995, *Ap. J.*, **450**, 163.

22. "Detection of Massive Forming Galaxies at Redshifts $z > 1$," L. L. Cowie, E. M. Hu, and A. Songaila 1995, *Nature*, **377**, 603.
23. "Hawaii 167 and Q0059-2735: Heavily Dust-Enshrouded Young QSOs," E. Egami, F. Iwamuro, T. Maihara, S. Oya, and L. L. Cowie 1995, *A. J.*, *in press*.